Preliminary Results from the Industrial Steam Market Assessment

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Abstract

This paper discusses fuel use and potential energy savings in the steam systems of three steam intensive industries: pulp and paper, chemical manufacturing, and petroleum refining. To determine the energy consumption to generate steam in these industries, a combined top-down and bottom-up approach was used. The top-down approach relied on data from the Manufacturing Consumption of Energy Survey (MECS) while the bottom-up approach assessed energy intensities of key processes and/or products in each industry. The results of the top-down approach indicate that to generate steam the pulp and paper industry used 2,221 trillion Btu, the chemical manufacturing industry used 1,548 trillion Btu, and the petroleum refining industry used 1,676 trillion Btu. The results of the bottom-up assessments indicate that these energy use estimates are reasonable. To determine the fuel savings available to each industry from steam system improvements, expert judgment was elicited. Preliminary results from the effort to determine potential steam system fuel savings are discussed.

Introduction

The U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE) BestPractices efforts aim to assist U.S. industry in adopting near-term energy-efficient technologies and practices through voluntary technical-assistance programs on improved system efficiency. There are nine industry groups—designated Industries of the Future (IOFs)—that are the focus of the OIT efforts. These IOFs include Agriculture, Aluminum, Chemicals, Forest Products, Glass, Metal Casting, Mining, Petroleum, and Steel. BestPractice efforts cover motor-driven systems such as pumps and fans, compressed air, steam, and process heating systems.

The overall goal of the BestPractices Steam effort is to assist steam users in adopting a systems approach to designing, installing, and operating boilers, distribution systems, and steam applications. In June 2000, Resource Dynamics Corp., under contract with the Oak Ridge National Laboratory (ORNL) with funding from DOE-OIT, initiated an Industrial Steam System Market Assessment. Two of the major goals of this Steam System Market Assessment effort were: 1) to develop baseline data on steam generation and use by the pulp and paper, petroleum refining, and chemical manufacturing industries; and 2) to develop baseline data on potential opportunities available for improving the energy efficiency of industrial steam systems for these three industries. This paper presents preliminary results from the steam market assessment effort.

Steam Generation, Use in the Pulp and Paper, Petroleum Refining, and Chemical Manufacturing Industries

Steam Generation

To estimate the amount of fuel used to generate steam for the pulp and paper, petroleum refining, and chemical manufacturing industries, we assessed data from Manufacturing Consumption of Energy Survey 1994 (MECS)[1]. MECS provides the most comprehensive data for fuel use in these industries, reporting fuel use data at the 4-digit SIC level. However, many of the data are missing or are omitted due to several possible reasons, including disclosure of competitive information, insufficient statistical confidence, and inadequate representation of data. Fortunately, in many instances, this data can be inferred using other tables and/or applying assumptions about industry processes. We inferred this missing data, then assessed how much fuel is used to generate steam.

MECS reports fuel use in three principal categories: "Indirect Uses—Boiler Fuel", "End use not reported" (EUNR), and "Conventional electricity generation." EUNR data primarily consist of "Other" fuels, which account for energy that is not included in the major energy source categories. Common examples of other fuel are coke, refinery gas, and wood chips. We allocated the fuel use data from these principal categories based on process characteristics of the pulp and paper, chemical manufacturing, and petroleum refining industries. For example, for the pulp and paper industry, EUNR data is allocated entirely to boiler fuels due to the steam intensive nature of the thermal processes in that industry. In the chemical industry, many production processes are direct-fired. For example, ethylene and propylene production require large amounts of fuel to fir pyrolysis furnaces. Similarly, in the petroleum industry, there are several processes that use waste fuels both to generate steam and to provide direct heating for other processes. To allocate the appropriate amount of "Other" fuel to steam generation for the chemical manufacturing and petroleum refining industries, we determined the amount of fuel used in direct-fired applications in these industries [2]. We then subtracted this fuel use from the "Other" fuel data.

Another component of fuel use that is included in the industry total for generating steam is conventional electricity generation. MECS provides data that indicate the amount of all on-site electric generation that is cogenerated for each industry. Combining this data with the assumption that the energy available to generate steam is 65 percent of the fuel used to generate electricity, provides an estimate of the fuel allocated to steam from "Conventional Electricity Generation." The results for these three fuel components are shown in Table 1.

To convert the fuel energy data into steam usage, estimates of the conversion efficiencies are required. The average boiler efficiencies for each industry were determined based on the distribution of fuel types [3] as indicated by MECS. For example, the combustion efficiency of boilers that use fuels such as bark and black liquor was estimated at 65 percent, while the combustion efficiency of boilers that burn coal was estimated at 81 percent. Table 2 provides the result of this conversion for these three industries.

Pulp and Paper Industry Steam Use

Estimates of the process steam requirements of the pulp and paper industry are determined by a bottom up approach that evaluates the manufacturing processes. The basis for this approach uses the typical energy requirements for integrated facilities. Integrated facilities include all three major process steps—preparation, pulping, and paper or paperboard manufacturing—that are required to manufacture finished paper and paperboard products from logs. Preparation is the process of converting logs into wood chips that are small enough to be sent into the pulping process.

Table 1: Energy Consumed to Generate Steam by Industry

	SIC	Indirect Uses - Boiler Fuel	End Use Not Reported	Conventional Electricity Generation	Total
Pulp and Paper	**26**	**849**	**1,351**	**20**	**2,221**
Pulp Mills	2611	40	191	0	231
Paper Mills	2621	459	611	15	1,085
Paperboard Mills	2631	288	533	6	827
Other Pulp and Paper Segments		62	16	0	78
Chemicals	**28**	**1,229**	**184**	**127**	**1,540**
Alkalies and Chlorine	2812	51	30	0	81
Inorganic Pigments	2816	10	10	0	20
Inorganic Chemicals	2819	101	23	1	126
Plastics and Resins	2821	137	50	0	187
Synthetic Rubber	2822	23	9	0	32
Organic Fibers, Noncellulosic	2824	72	8	0	80
Cyclic Crudes and Intermediates	2865	81	27	3	111
Organic Chemicals	2869	389	11	88	488
Nitrogenous Fertilizers	2873	72	13	1	86
Other Chemical Segments		293	3	34	330
Petroleum	**29**	**304**	**1,323**	**47**	**1,675**
Petroleum Refining	2911	295	1,313	47	1,655
Other Petroleum Refining Segments		9	11	0	20

Units are trillion Btus

Table 2: Estimated Steam Generation by Industry

	SIC	Indirect Uses - Boiler Fuel	End Use Not Reported	Conventional Electricity Generation	Total
Pulp and Paper	**26**	**527,857**	**840,094**	**14,153**	**1,382,103**
Pulp Mills	2611	23,617	112,891	0	136,509
Paper Mills	2621	278,992	371,382	10,400	660,774
Paperboard Mills	2631	177,308	328,143	4,070	509,520
Other Pulp and Paper Segments		47,939	27,678	0	75,301
Chemicals	**28**	**841,277**	**125,952**	**88,348**	**1,055,577**
Alkalies and Chlorine	2812	34,396	20,233	0	54,629
Inorganic Pigments	2816	6,870	6,938	0	13,808
Inorganic Chemicals	2819	69,892	16,054	904	86,851
Plastics and Resins	2821	92,505	33,761	45	126,311
Synthetic Rubber	2822	15,726	6,154	0	21,880
Organic Fibers, Noncellulosic	2824	50,450	5,707	0	56,157
Cyclic Crudes and Intermediates	2865	55,643	18,548	1,809	76,000
Organic Chemicals	2869	257,687	7,287	61,217	326,191
Nitrogenous Fertilizers	2873	50,895	9,189	904	60,988
Other Chemical Segments		207,213	2,081	23,468	232,762
Petroleum	**29**	**207,052**	**901,063**	**32,696**	**1,140,811**
Petroleum Refining	2911	200,857	893,709	32,696	1,127,262
Other Petroleum Refining Segments		6,196	7,353	0	13,549

Units are million lbs. of steam

Pulping is the process of obtaining fibers from the wood. Paper or paperboard manufacturing forms these fibers into final products. Table 3 shows the range of thermal and electric energy use for integrated plants [3].

Most paper and paperboard products can be grouped into 14 categories. Production processes can be allocated to these product categories. Assigning production processes—and the energy usage associated with them—to these product classes provides one way of estimating thermal energy use for each product class [4].

In pulp and paper manufacturing, thermal energy is provided almost entirely by steam. Consequently, multiplying the thermal energy required for each ton of product by the tons of product produced determines the total amount of steam required by the industry. To determine the amount of fuel needed to generate this steam, a conversion factor must be applied. This conversion accounts for losses in burning the fuel, generating the steam, and distributing it to the end uses. For this report, a fuel to steam conversion efficiency of 75 percent was assumed. As indicated in Table 4, the total thermal energy requirement for the

Table 3: Thermal and Electric Energy Use for Integrated Pulp and Paper Plants

Process Energy for Integrated Mills	Thermal		Electrical		Total	
	Min	Max	Min	Max	Min	Max
Chemical (Kraft and Sulfite)	16,000	33,000	2,400	5,500	18,400	38,500
Mechanical	8,000	25,000	6,500	17,200	14,500	42,000
Sulfite semi-chemical	17,000	35,000	4,100	6,800	21,000	41,800
Chemi-thermal mechanical	9,000	25,000	7,500	16,400	16,500	41,400

Thousand Btus/ton

Table 4: Pulp and Paper Thermal Energy Requirements by Product Type

Energy Consumption by Product		Production	Thermal Energy Consumption		
		(Thousand short tons)	(Trillion Btus)		
	Product		Min	Max	Ave
Paper Products	Newsprint	6,984	54	173	113
	Groundwood printing & converting	1,915	15	47	31
	Coated paper	8,804	141	291	216
	Uncoated free sheets	13,304	213	439	326
	Bleached bristols	1,383	22	46	34
	Cotton fiber	159	3	5	4
	Thin papers	149	2	5	4
	Tissue	6,098	98	201	149
	Unbleached kraft	2,308	30	69	50
	Bleached, specialty packaging	2,417	39	80	59
Paper Board	Unbleached kraft paperboard	22,468	292	674	483
	Solid bleached paperboard	5,029	80	166	123
	Semichemical paperboard	5,943	101	208	155
	Recycled paperboard	12,283	123	332	227
		Total	**1,212**	**2,735**	**1,974**

pulp and paper industry was 1,980 trillion Btu. Applying a 75 percent conversion factor results in an estimated boiler fuel use of 2,640 (= 1,980/0.75) trillion Btu.

MECS indicates that the fuel used to generate steam in the pulp and paper industry was 2,221 trillion Btu (refer to Table 1), which is about 16 percent less than the 2,640 trillion Btu estimate. Although many assumptions are built into this model, the relative agreement between these data indicates that these assumptions are reasonable.

Petroleum Refining Industry Steam Use

The petroleum refining industry uses energy to convert crude oil into many different products, some of which are used directly by consumers, while others are feedstocks for other industries. Petroleum refining uses a series of processes to produce these products. Combining the energy required by each process and the amount of product that was produced by each process provides an estimate of the total amount of energy used by the industry. Additionally, the component energy types, including direct-fired, electric, and steam, can be disaggregated from the energy data for each refining process [2]. This allocation allows the total steam use within the industry to be evaluated against the amount of fuel used to generate steam as indicated by MECS.

Table 5 describes the average energy requirements of the key refining processes by technology and combines production estimates to calculate overall industry energy use [5,6]. The total steam energy use is estimated to be 1,071 trillion Btu. If the steam system efficiency is 75 percent, then the fuel use that corresponds to this energy estimate is 1,428 trillion Btu.

To evaluate the accuracy of the "energy use by process" approach, recall that the MECS estimate for the amount of fuel used to generate steam in the petroleum refining industry was 1,676 trillion Btu. The resulting difference is 248 trillion Btu or about 15 percent. In relative terms the "energy use by process" approach indicates that steam represents 46 percent (= 1,071/2,333) of the total energy use, while MECS indicates that the fuel used to generate steam represents about 53 percent of the industry fuel use.

Table 5: Energy Use Requirements of Common Refinery Processes

			Energy Use by Technology (Trillion Btus)			
Process	Average Unit Energy Use (Thousand Btus/bbl)	Production (Thousand bbls/day)	Direct Fired	Electric	Steam	Total
Atmospheric Distillation	114	14,584	383	12.3	246.1	641.7
Vacuum Distillation	92	6,433	113	2.8	123.3	238.8
Visbreaking	87	65	3	0.7	(1.3)	2.1
Coking Operations	170	1,771	110	14.1	(9.4)	115.1
Fluid Catalytic Cracking	100	5,051	166	23.4	114.4	189.8
Catalytic Hydrocracking	240	1,261	62	18.2	33.6	113.9
Catalytic Hydrotreating	120	7,912	202	54.6	212.0	468.7
Catalytic Reforming	284	3,692	243	13.5	117.2	373.2
Alkylation	375	1,157	-	10.9	139.5	150.4
Isomerization	-	-			-	-
Isobutane	359	101	-	0.4	12.4	12.8
Isopentane/Isohexane	175	434	-	0.9	25.9	26.8
		Total	**1,283**	**152**	**1,014**	**2,333**

Chemical Manufacturing Industry Steam Use

The chemical manufacturing industry uses energy to manufacture over 70,000 products for consumer and industrial markets. Although the chemical industry manufactures a wide range of products, a relatively small number of them account for most of the industry energy use. As a result, evaluating the processes for manufacturing these high energy-use chemical products can provide a reasonable assessment of how much energy, specifically steam energy, is used [7,8].

As shown in Table 6, there are 20 chemical products whose process steam energy requirements account for 824 trillion Btu of steam.

This study used a 75 percent conversion efficiency to account for losses in converting fuel to thermal energy, generating steam and delivering it to the end uses. This conversion factor produces a fuel use estimate of 1,099 trillion Btu. Since MECS indicates that the chemical industry used about 3,273 trillion Btu of energy [2], of which steam energy accounts for roughly 1,548 trillion Btu, evaluating the process energy requirements of these 20 chemical products accounts for about 71 percent of the total chemical manufacturing industry steam use.

Developing Baseline Steam Performance Improvement Opportunity Data

To determine the potential savings from improving steam system efficiency and performance, we determined that expert elicitation would be the most effective approach. Experts with experience in the steam systems at multiple industrial facilities are able to provide data that is representative of industry conditions. An optional approach is to survey a representative sample of industrial facilities in the subject industries. However, steam systems are often very expansive. Gathering enough data to assess each system adequately—even in a representative sample of facilities—would be prohibitively costly.

Effective expert elicitation requires asking the right people the right questions. To find the right people, we sought a set of qualified experts. These contacts were made through:

- The BestPractices Steam program,
- Referrals by other industry stakeholders, and
- Industry research.

Table 6: Steam Energy to Make Selected Chemical Products

Chemical	SIC	Production (Million lbs)	Unit Steam Energy (Btu/lb)	Total Steam Energy (Trillion Btu)	Total Energy (Trillion Btu)
Ethylene	2869	44,534	7,695	343	406
Ammonia	2873	15,788	5,062	80	274
Ethylbenzene/Styrene	2865	11,270	15,000	169	190
Polystyrene	2821	7,620	2,123	16	17
Chlorine/Sodium Hydroxide	2812	25,078	2,909	73	197
Ethylene Dichloride/Polyvinyl Chloride	2821	14,818	1,648	24	34
Phenol/Acetone	2865	4,054	7,459	30	32
Benzene, Toluene, and Xylene	2865	28,118	342	10	12
Caprolactum	2824	1,508	9,691	14.6	18
Sodium Carbonate	2812	20,552	2,683	55	79
Polybutadiene Rubber	2822	550	1,584	0.9	10
Styrene Butadiene Rubber	2822	2,497	2,049	5	7
Butyl Rubber	2822	431	638	0.3	7
Cyclohexane	2865	2,108	1,593	3	4
			Totals	**824**	**1,287**

Prospective participants were contacted to determine their level of knowledge and experience in the steam systems of the subject industries. After describing the objectives of this project and assessing the qualifications of the prospective participants, we requested qualified experts to provide responses regarding estimates of steam system energy savings.

To ask the right questions regarding these savings, we developed a list of 30 performance improvement opportunities, which are listed below:

- Minimize Boiler Combustion Loss by Optimizing Excess Air
- Improve Boiler Operating Practices
- Repair or Replace Burner Parts
- Install Feedwater Economizers
- Install Combustion Air Preheaters
- Improve Water Treatment
- Clean Boiler Heat Transfer Surfaces
- Improve Blowdown Practices
- Install Continuous Blowdown Heat Recovery
- Add/Restore Boiler Refractory
- Establish the Correct Vent Rate for Deaerator
- Reduce Steam System Generating Pressure
- Improve Quality of Delivered Steam
- Implement an Effective Steam Trap Maintenance Program
- Ensure Steam System Piping, Valves, Fittings, and Vessels are Well Insulated
- Minimize Vented Steam
- Repair Steam Leaks
- Isolate Steam from Unused Lines
- Improve System Balance
- Improve Plant Wide Testing and Maintenance Practices
- Optimize Steam Use in Pulp and Paper Drying Applications
- Optimize Steam Use in Pulp and Paper Air Heating Applications
- Optimize Steam Use in Pulp and Paper Water Heating Applications
- Optimize Steam Use in Chemical Product Heating Applications
- Optimize Steam Use in Chemical Vacuum Production Applications
- Optimize Steam Use in Petroleum Refining Distillation Applications
- Optimize Steam Use in Petroleum Refining Vacuum Production Applications
- Improved Condensate Recovery
- Use High Pressure Condensate to Generate Low Pressure Steam
- Implement a Combined Heat and Power (Cogeneration) Project

The principal data that are necessary for assessing each improvement opportunity are:

- Fuel savings,
- Percentage of facilities for which each opportunity is feasible,
- Payback period, and
- Reasons for implementing the opportunity. This response provides insight into why the improvement opportunity is usually implemented.

We determined that the best tool to elicit expert knowledge regarding these opportunities was a questionnaire. A questionnaire provides several advantages, including flexibility in devoting time to complete it, allowing research, and permitting write-in comments. Before sending the questionnaire to the experts, it was reviewed by a separate group of industry stakeholders. The questionnaire was reviewed and modified until it met three important objectives:

- Is it user friendly?
- Are the questions unambiguously worded?
- Do the responses gather accurate and representative data?

The questionnaire was sent to 34 people who agreed to participate. Nineteen of the participants returned the questionnaire with useful data. After the questionnaires were returned and the data extracted, several different approaches were considered to statistically evaluate the collected data.

There were also several approaches considered in presenting the data. One method groups the data by industry; another presents combined data for all three industries. Although most of the experts indicated that they have more experience in some industries than others, there was little distinction among the estimates of the fuel savings, feasibility percentages, and paybacks for each industry.

Lower and upper uncertainty values characterize the range of differences among the experts' responses. Lower and upper certainty values of 2.5 and 97.5 percentile respectively were selected. A large difference between the upper and lower uncertainty estimates indicates that there was a wide range among responses of the experts. Conversely, a small difference indicated a relatively close agreement among the experts.

At the time this paper was prepared, the results have not received sufficient industry review to allow presentation of the final data. However, we can note the following, based on evaluation of the results from the experts who participated:

- Estimated fuel savings for the 30 identified performance improvement opportunities ranged from 0.6 percent to 5.2 percent;
- Percent of facilities for which the performance opportunities are feasible ranged from three percent to 31percent; and
- Estimated payback periods for the performance improvement opportunities ranged from three to 36 months.

Conclusions and Future Efforts

Once the full results of this effort have received sufficient industry review, a Steam System Market Assessment report will be prepared. This report will include the detailed results on steam generation and use and steam system performance opportunities available for the pulp and paper, petroleum refining, and chemical manufacturing industries. These results will provide baseline data for the key opportunities available for improving industrial steam system energy efficiency.

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